

Commission 47: Cosmology

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Abstract. 2002–2005 has seen rapid progress in cosmology with the publication of the 1st year WMAP results and analyses of large scale red-shift surveys, ushering in an era of “precision cosmology”. There has been steady progress, too, in the discovery and study of quasars and galaxies in the early Universe.

1. Major Scientific Developments

The period 2002–2005 has seen major developments in the field of Cosmology. There has been a substantial consolidation of confidence in the parameters of the so-called “concordance cosmology” (i.e. approximately $\Omega_B \sim 0.04$, $\Omega_{CDM} \sim 0.23$ and $\Omega_{DE} \sim 0.73$, with $H_0 \sim 70 \text{ kms}^{-1}\text{Mpc}^{-1}$), establishing a new era of precision cosmology. Despite this, however, the physical nature of the dark matter and dark energy remain unknown and as mysterious as ever. There has also been continuing steady progress in observations of objects at very high redshift and new evidence concerning the re-ionization history of the intergalactic medium.

1.1. WMAP and Precision Cosmology

Publication of the first-year results from the WMAP satellite occurred in 2003 (Bennet *et al.* 2003) and represents a landmark in cosmology. Although the main results to a large degree confirm earlier work (e.g. from the Boomerang balloon experiment) the WMAP 1st year data have led to a substantial reduction in the uncertainties in the parameters describing the Λ -CDM “concordance” cosmology (Spergel *et al.* 2003), especially in conjunction with new measurements of large scale structure in the present day Universe (i.e. the 2dfGRS and SDSS redshift surveys, see e.g. Cole *et al.* 2005), of the SN1a Hubble diagram (e.g. Strolger *et al.* 2004) and other measurements such as the power spectrum of the Lyman α forest at high redshifts. The emergence of the high precision concordance cosmology was identified by the editors of Science Magazine as the “science breakthrough” of 2003.

The concordance cosmology has been impressively robust for the many independent analyses that have all indicated its validity, and at the present time it is unchallenged, at least as an empirical description of the Universe. Dark Matter, while familiar to cosmologists for some time, almost certainly represents physics beyond the Standard Model, while the Dark Energy component potentially has even greater significance for fundamental Physics. Despite the solid evidence for both components, there is no clear indication of the nature of either at the present time. Attempts to unify Dark Matter and Dark Energy as different aspects of the same entity are attracting attention but have yet to produce convincing answers, while the intriguing idea that the appearance of cosmic acceleration might be explained via the “old physics” of super-horizon back-reaction appears unpromising.

New very large observational surveys are now being designed with the ambitious aim of measuring with high precision w , the equation of state of Dark Energy, which may hold clues as to its nature, especially if $w \neq 1$.

1.2. *The first objects in the Universe and early re-ionization*

The redshifts of the most distant objects have crept up over the last three years from $z \sim 5.8$ to $z \sim 6.5$ (Hu *et al.* 2002, Kodaira *et al.* 2003), for both quasars and galaxies. The present limit almost certainly arises from the practical difficulties of observations at wavelengths beyond $1 \mu\text{m}$: $z \sim 6.5$ places Lyman α in the last atmospheric window before $1 \mu\text{m}$. Almost certainly young galaxies and quasars remain to be found at higher redshifts as soon as these difficulties can be overcome. Not least the observation of significant enrichment, including large reservoirs of CO molecular gas (Walter *et al.* 2004), in the quasars makes clear that these are in no way “primordial” objects. Searches for objects at $7 < z < 10$ with the HST are now underway.

The spectra of $z \sim 6$ quasars show a deep Gunn-Peterson trough, indicating a steady increase in the neutral fraction in the intergalactic medium with redshift and prompting a lively, but as yet inconclusive, debate as to whether the IGM at $z \sim 6.4$ is in fact largely neutral. Large angle polarization in the WMAP measurements (Kogut *et al.* 2003) has indicated a significant ($\tau \sim 0.17$) “foreground” scattering of the cosmic microwave background, suggesting that a first re-ionization of the Universe may have occurred at high redshifts, $z \sim 17$. This observation, for which confirmation is eagerly awaited, has prompted several theoretical investigations of how early and extended periods of re-ionization can be achieved.

Looking ahead, the approval of the LOFAR project and other competing projects has focused theoretical attention on the possibilities of using 21cm radiation as a new cosmological probe.

1.3. *Evolution of the galaxies and AGN*

There has been similar steady progress in identifying and studying galaxies at high redshifts. It is by now likely that all major galaxy populations have been identified, at least to redshifts as high as $z \sim 3$, even if their detailed properties and relative importance are not in every case completely clear. Spectroscopic confirmation of the redshifts of the high redshift Ultra-Luminous Infrared Galaxies (ULIRGs) detected in sub-mm surveys has firmly established the importance of these objects in the high redshift Universe ($2 < z < 4$).

There has been a growing appreciation of the importance of so-called “cosmic variance” in the statistical study of high redshift galaxies in narrow pencil beam surveys. Partly in response, several wide-field redshift surveys including the VVDS, COMBO-17/GEMS and DEEP-2 that have recently been completed. The next step in this direction will be the COSMOS survey started in 2003.

Much of the attention has focused on the number density and properties of massive galaxies at high redshift, since these may pose the clearest problems for hierarchical models of galaxy formation. Significant developments in the last three years have included the detection of passive galaxies at high redshift in several surveys, including the FIRES and GDDS surveys (Glazebrook *et al.* 2004, Förster-Schreiber *et al.* 2004), and attempts at quantifying the stellar masses of high redshift galaxies, especially using Spitzer measurements. The first attempts at kinematic measurements of galaxy masses at high redshift using sub-millimeter molecular line observations (e.g. Genzel *et al.* 2003) have been a preview of what will be possible with ALMA. Partly in response to these observational developments, there has been continuing development of phenomenological

“semi-analytic models” of galaxy evolution, including increased attention to the potential role of feedback from AGN activity in controlling star-formation in galaxies.

2. Conferences

The large number of international conferences in the area of Cosmology attests to the vigorous activity in this research field. The following is a list extracted from the compilation of Liz Bryson at CFHT, and is by no means complete, excluding for instance many of the conferences and workshops devoted to Galaxy Formation and Evolution (see the Report for IAU Commission 28).

2.1. IAU Symposia

- IAU Symposium 228 FROM LITHIUM TO URANIUM: ELEMENTAL TRACERS OF EARLY COSMIC EVOLUTION, Paris, France, May 23–27, 2005
- IAU Symposium 225 GRAVITATIONAL LENSING IMPACT ON COSMOLOGY, Lausanne, Switzerland, July 19–23, 2004
- IAU Symposium 220 DARK MATTER IN GALAXIES, Sydney, Australia, July 21–25, 2003
- IAU Symposium 217 RECYCLING INTERGALACTIC AND INTERSTELLAR MATTER, Sydney, Australia, July 14–17, 2003
- IAU Symposium 216 MAPS OF THE COSMOS, Sydney, Australia, July 14–17, 2003

2.2. IAU Colloquia

- IAU Colloquium 199 PROBING GALAXIES THROUGH QUASAR ABSORPTION LINES, Shanghai, China RP, March 14–18, 2005
- IAU Colloquium 198 NEAR-FIELD COSMOLOGY WITH DWARF ELLIPTICAL GALAXIES, Les Diablerets, Switzerland, March 14–18, 2005
- IAU Colloquium 195 OUTSKIRTS OF GALAXY CLUSTERS: INTENSE LIFE IN THE SUBURBS, Torino, Italy, March 12–16, 2004

2.3. Other conferences and workshops

- XVIIIth IAP Colloquium : On the Nature of Dark Energy, Monday, 1 July 2002–Friday, 5 July 2002, Paris, Institut d’Astrophysique de Paris
- Astronomy and Beyond: Astrophysics, Cosmology and Astrobiology-The G. Gamow’s Odessa Astronomical Summer School for Young Scientists, Monday, 12 August 2002–Saturday, 17 August 2002, Odessa, Ukraine
- The New Cosmology Confronts Observation (attendance limited), Monday, 19 August 2002–Friday, 23 August 2002, Kavli Institute for Theoretical Physics
- Third Tropical Workshop on Particle Physics and Cosmology: Neutrinos, Branes and Cosmology, Monday, 19 August 2002–Saturday, 24 August 2002, San Juan, Puerto Rico
- XI IAGUSP Advanced School on Astrophysics: High Energy Astrophysics and Cosmology, Sunday, 1 September 2002–Friday, 6 September 2002, Campos do Jordao, Sao Paulo, Brazil
- 4th International Workshop on the Identification of Dark Matter-IDM2002, Monday, 2 September 2002–Friday, 6 September 2002, York, UK
- The Cosmology of Extra Dimensions and Varying Fundamental Constants, Tuesday, 3 September 2002–Thursday, 5 September 2002, Porto, Portugal
- Chalogne School, 9th Course: The Early Universe and the Cosmic Microwave Background: Theory and Observations, Saturday, 7 September 2002–Wednesday, 18 September 2002, Palermo-Sicily, Italy

- COSMO-02: International Workshop on Particle Physics and the Early Universe, Wednesday, 18 September 2002–Saturday, 21 September 2002, Chicago, Illinois
- The Emergence of Cosmic Structure, Monday, 7 October 2002–Wednesday, 9 October 2002, College Park, Maryland
- Carnegie Observatories Centennial Symposium I: CO-evolution of Black Holes and Galaxies, Sunday, 20 October 2002–Friday, 25 October 2002, Carnegie Observatories, Pasadena, CA.
- Structure Evolution and Cosmology: New Synergy between Ground-based Observations, Space Observations and Theory, Monday, 28 October 2002–Thursday, 31 October 2002, Santiago, Chile
- Challenges to the Standard Paradigm: Fundamental Physics and Cosmology, Friday, 1 November 2002–Sunday, 3 November 2002, Arnold and Mabel Beckman Center of the National Academy of Sciences, UC Irvine c
- Carnegie Observatories Centennial Symposium II: Measuring and Modeling the Universe, Sunday, 17 November 2002–Friday, 22 November 2002, Carnegie Observatories, Pasadena, CA
- XIV Canary Islands Witer School of Astrophysics-Dark Matter and Dark Energy in the Universe, Monday, 18 November 2002–Friday, 29 November 2002, Puerto de la Cruz, Tenerife, Canary Island, Spain
- CMB & Cosmology: Where Are We?, Monday, 2 December 2002–Friday, 6 December 2002, Ringberg Castle, Bavaria (Germany)
- Gravitational Lensing : a Unique Tool for Cosmology, Sunday, 5 January 2003–Saturday, 11 January 2003, Aussois, Savoie, France
- The Baryonic Universe, Sunday, 12 January 2003–Saturday, 18 January 2003, Aspen Center for Physics
- Advances of Modern Cosmology, Thursday, 23 January 2003–Thursday, 23 January 2003, St.Petersburg, Russia
- Carnegie Observatories Centennial Symposium III: Clusters of Galaxies: Probes of Cosmological Structure and Galaxy Evolution, Sunday, 26 January 2003–Friday, 31 January 2003, Carnegie Observatories, Pasadena, CA
- Carnegie Observatories Centennial Symposium IV: Origin and Evolution of the Elements, Sunday, 16 February 2003–Friday, 21 February 2003, Carnegie Observatories, Pasadena, CA
- IPM School on Cosmology 2003: The High Z-Universe and Weak Lensing, Saturday, 1 March 2003–Thursday, 13 March 2003, Qeshm Island, Tehran, IRAN
- 1st Oxford-Princeton Workshop on Cosmology, Monday, 17 March 2003–Tuesday, 18 March 2003, Princeton University
- Workshop on the Topology of Re-ionization, Thursday, 20 March 2003–Saturday, 22 March 2003, Tucson, AZ
- The Davis Meeting on Cosmic Inflation, Saturday, 22 March 2003–Tuesday, 25 March 2003, Davis, CA
- 33rd Saas-Fee Course on Gravitational Lensing: Strong, Weak and Micro, Monday, 7 April 2003–Saturday, 12 April 2003, Les Diablerets, Vaud, Switzerland
- XII-th International School:Particles and Cosmology, Monday, 21 April 2003–Saturday, 26 April 2003, Baksan Valley, Kabardino-Balkaria, Russian Federation
- Great Lakes Cosmology VII, Thursday, 15 May 2003–Sunday, 18 May 2003, Ann Arbor, MI USA
- Aspen Summer Workshop on Cosmology and Astrophysics with Galaxy Clusters, Monday, 26 May 2003–Friday, 13 June 2003, Aspen, CO

- Physical Cosmology, Sunday, 15 June 2003–Friday, 20 June 2003, Blois, Loire Valley, France
- Multi-Wavelength Cosmology, Tuesday, 17 June 2003–Friday, 20 June 2003, Mykonos Island, Greece
- Which Model(s) for the Early Universe ? (8th Claude Itzykson meeting), Wednesday, 18 June 2003–Friday, 20 June 2003, CEA-Saclay, France
- Where Cosmology and Fundamental Physics Meet, Monday, 23 June 2003–Thursday, 26 June 2003, Marseilles France
- Hyperbolic Models in Astrophysics and Cosmology, Monday, 23 June 2003–Friday, 27 June 2003, Newton Institute of Mathematical Sciences, Cambridge
- EOTVOS Graduate Course in Physics: Common Trends in Cosmology and Particle Physics, Monday, 23 June 2003–Sunday, 29 June 2003, Lake Balaton, Hungary
- Gravitation, Cosmology and Relativistic Astrophysics, Monday, 23 June 2003–Friday, 27 June 2003, Kharkov National University, Kharkov, Ukraine
- Fifth J.J. Giambiagi Winter School: Precision Cosmology, Monday, 28 July 2003–Friday, 1 August 2003, Physics Department, University of Buenos Aires, Argentina
- Third Ulyanovsk International School-Seminar : Problems of Theoretical and Observational Cosmology UISS-2003, Monday, 1 September 2003–Wednesday, 10 September 2003, Russia, Ulyanovsk
- Villa Mondragone International School on Gravitation and Cosmology, Saturday, 6 September 2003–Thursday, 11 September 2003, Monte Porzio Catone (Roma) Italy
- Conference on Statistical Problems in Particle Physics, Astrophysics, and Cosmology, Monday, 8 September 2003–Thursday, 11 September 2003, Stanford Linear Accelerator Center, Menlo Park, California
- Second Aegean Summer School on the Early Universe, Monday, 22 September 2003–Tuesday, 30 September 2003, Ermoupolis, Syros Island, Greece
- 6th RESCEU International Symposium :Frontier in Astroparticle Physics and Cosmology, Tuesday, 4 November 2003–Friday, 7 November 2003, Sanjo Conference Hall, The University of Tokyo, (Tokyo, Japan)
- International Conference on Gravitation and Cosmology, Monday, 5 January 2004–Saturday, 10 January 2004, Kochi, Kerala, India
- Workshop on Studies of Dark Energy and Cosmology with X-ray Surveys, Thursday, 15 January 2004–Friday, 16 January 2004, Greenbelt Marriott, Greenbelt, MD. USA
- The Large-scale Distribution of Mass and Light in the Universe, Monday, 19 January 2004–Saturday, 24 January 2004, Aspen Center for Physics, Aspen, Colorado, USA
- Cosmology and High Energy Astrophysics (Zeldovich-90), Tuesday, 20 January 2004–Friday, 24 December 2004, Space Research Institute, Moscow, Russia
- Observing Dark Energy, Thursday, 18 March 2004–Saturday, 20 March 2004, Tucson, AZ
- 2004 Mitchell Symposium on Observational Cosmology, Monday, 12 April 2004–Friday, 16 April 2004, Texas AM University
- Beyond Einstein: From the Big Bang to Black Holes, Monday, 10 May 2004–Friday, 14 May 2004, Stanford Linear Accelerator, Menlo Park, California
- Wide-Field Imaging from Space, Sunday, 16 May 2004–Tuesday, 18 May 2004, Berkeley, CA
- Santa Clara 2004. First International Workshop on Gravitation and Cosmology, Monday, 31 May 2004–Thursday, 3 June 2004, School of Mathematics, Physics and Computer Sciences. Las Villas Central Univers
- 1604-2004. Supernovae as Cosmological Lighthouses, Wednesday, 16 June 2004–Saturday, 19 June 2004, Padua, Italy

- Growing black holes: Accretion in a cosmological context, Monday, 21 June 2004–Friday, 25 June 2004, Garching bei Munchen, Germany
- XXeme Colloque de l'IAP : On the CMB, Monday, 28 June 2004–Friday, 2 July 2004, Institut d'Astrophysique de Paris
- Sixth Alexander Friedmann International Seminar on Gravitation and Cosmology, Monday, 28 June 2004–Saturday, 3 July 2004, Institut d'Etudes Scientifiques de Cargse (Corse) France
- The Quest for a Concordance Cosmology and Beyond, Monday, 5 July 2004–Friday, 9 July 2004, Institute of Astronomy, Cambridge
- Background Microwave Radiation and Intra-cluster Cosmology, Tuesday, 6 July 2004–Friday, 16 July 2004, Varenna, Italy
- Phi in the Sky: The Quest for Cosmological Scalar Fields, Thursday, 8 July 2004–Saturday, 10 July 2004, Porto, Portugal
- Astrophysics and Cosmology after Gamow–Theory and Observations, Sunday, 8 August 2004–Saturday, 14 August 2004, Odessa National University, Odessa, Ukraine
- Chemical Enrichment of the Early Universe, Monday, 9 August 2004–Friday, 13 August 2004, Santa Fe, NM
- Identification of Dark Matter 2004, Monday, 6 September 2004–Friday, 10 September 2004, Edinburgh, Scotland, United Kingdom
- Data Analysis in Cosmology, Monday, 6 September 2004–Friday, 10 September 2004, Valencia (Spain–Europe)
- JENAM '04 : The Many Scales in the Universe, Monday, 13 September 2004–Friday, 17 September 2004, Granada, Spain
- AG 2004: 78th Annual Scientific Meeting of the Astronomische Gesellschaft: From Cosmological Structures to the Milky Way, Monday, 20 September 2004–Saturday, 25 September 2004, Technical University of Prague, Czech Republic
- Massive Galaxies over Cosmic Time, Monday, 27 September 2004–Wednesday, 29 September 2004, STScI, Baltimore, MD, USA
- The Magnetized Plasma in Galaxy Evolution, Monday, 27 September 2004–Friday, 1 October 2004, Krakow, Poland
- Fifth International Conference on Dark Matter in Asto and Particle Physics (DARK2004), Sunday, 3 October 2004–Saturday, 9 October 2004, Texas AM University, College Station TX, USA
- The Cool Universe: Observing Cosmic Dawn. 2004 IAOC International Workshop, Monday, 4 October 2004–Friday, 8 October 2004, Universidad Santa Maria, Valparaiso, Chile
- Baryons in Dark Matter Haloes, Tuesday, 5 October 2004–Saturday, 9 October 2004, Novigrad, Istria (Croatia)
- Origins: From First Objects to Extrasolar Planets, Monday, 1 November 2004–Saturday, 6 November 2004, Nishinomiya and Kyoto, Japan
- Magnetic Fields in the Universe: From Laboratory and Stars to Primordial Structures, Sunday, 28 November 2004–Friday, 3 December 2004, Angra dos Reis, Brazil
- Arizona/Heidelberg Symposium: The High Redshift Frontier, Tuesday, 30 November 2004–Friday, 3 December 2004, Tucson, AZ, USA
- 2nd Advanced Chilean School of Astrophysics: First Large Scale Structures in the Universe and their Evolution, Monday, 6 December 2004–Friday, 10 December 2004, Departamento de Astronomia y Astrofisica, Pontificia Universidad Catolica, Santi
- Fundamental Physics from Clusters of Galaxies, Thursday, 9 December 2004–Saturday, 11 December 2004, Fermilab

- 22nd Texas Symposium on Relativistic Astrophysics, Monday, 13 December 2004–Friday, 17 December 2004, Stanford/Palo Alto, CA USA
- Cosmology and High Energy Astrophysics (Zeldovich-90), Monday, 20 December 2004–Friday, 24 December 2004, Space Research Institute, Moscow
- Gravitational Lensing, Dark Matter, and Dark Energy, Wednesday, 5 January 2005–Friday, 7 January 2005, Ohio State University, Columbus, Ohio, USA
- IPM School on Cosmology 2005 : The High Z Universe and Weak Lensing, Sunday, 16 January 2005–Monday, 24 January 2005, Queshm Island, Iran
- Surveying the Universe: Spectroscopic and Imaging Surveys for Cosmology, Saturday, 12 February 2005–Saturday, 19 February 2005, Obergurgl, near Innsbruck, Austria
- 6dF Galaxy Survey–Workshop 2005, Tuesday, 26 April 2005–Wednesday, 27 April 2005, Anglo-Australian Observatory, Sydney, Australia
- Relativistic Astrophysics, Monday, 2 May 2005–Friday, 6 May 2005, Institute for Pure and Applied Mathematics, UCLA, Los Angeles, California, USA
- Nonlinear Cosmology: Turbulence and Fields, Monday, 9 May 2005–Thursday, 12 May 2005, ICTP (Trieste, Italy)
- First Light and Re-ionization: Theoretical Study and Experimental Detection of First Luminous Sources, Thursday, 19 May 2005–Saturday, 21 May 2005, Beckman Center, University of California, Irvine, CA, USA
- Computational Cosmology, Tuesday, 31 May 2005–Saturday, 4 June 2005, Trieste, Italy
- 3rd Advanced Research Workshop-Gravity, Astrophysics, and Strings at the Black Sea, Monday, 13 June 2005–Monday, 20 June 2005, Resort of Kiten, Bulgaria
- Extra-galactic Workshop: After the First Stars, Wednesday, 15 June 2005–Thursday, 16 June 2005, Nottingham, UK
- Workshop on Surveys of Dark Energy, Tuesday, 21 June 2005–Tuesday, 21 June 2005, ICG, Portsmouth, UK

3. Recent Review Articles

- ACTION AT A DISTANCE AND COSMOLOGY: A Historical Perspective, J.V. Narlikar, *Annual Review of Astronomy and Astrophysics*, Vol. 41: 169–189
- WEAK GRAVITATIONAL LENSING BY LARGE-SCALE STRUCTURE, Alexandre Refregier, *Annual Review of Astronomy and Astrophysics*, Vol. 41: 645–668
- THE COSMOLOGICAL CONSTANT AND DARK ENERGY, Peebles, P.J., Bharat, Ratra, *Reviews of Modern Physics*, Vol 75, 2, 559–606.
- MEASURING AND UNDERSTANDING THE UNIVERSE, Freedman, W.L. & Turner, M.S., *Reviews of Modern Physics*, Vol 75, pp1433–1447.
- THE FIRST STARS, Volker Bromm & Richard B. Larson, *Annual Review of Astronomy and Astrophysics*, Vol. 42: 79–118
- EROS AND FAINT RED GALAXIES, Patrick J. McCarthy, *Annual Review of Astronomy and Astrophysics*, Vol. 42: 477–515
- SCALING LAWS IN THE DISTRIBUTION OF GALAXIES, B.T. Jones, V.J. Martinez, E. Saar, V. Trimble, *Reviews of Modern Physics*, Vol 76, pp1211–1266.
- MOLECULAR GAS AT HIGH REDSHIFT, P.M. Solomon, P.A. Vanden Bout, *Annual Review of Astronomy and Astrophysics*, Vol. 43: 677–725
- DUSTY INFRARED GALAXIES: Sources of the Cosmic Infrared Background, Guilaine Lagache, Jean-Loup Puget & Herv Dole, *Annual Review of Astronomy and Astrophysics*, Vol. 43: 727–768
- DEEP EXTRAGALACTIC X-RAY SURVEYS, W.N. Brandt & G. Hasinger, *Annual Review of Astronomy and Astrophysics*, Vol. 43: 827–859

- TRACING COSMIC EVOLUTION WITH CLUSTERS OF GALAXIES, G. Mark Voit, *Reviews of Modern Physics*, Vol 77, pp207–258.
- DAMPED LY α SYSTEMS, Arthur M. Wolfe, Eric Gawiser, Jason X. Prochaska, *Annual Review of Astronomy and Astrophysics*, Vol. 43: 861–918

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Cole, S., and 30 co-authors, 2005, *MNRAS*, 362, 505.
Förster-Schreiber and 14 co-authors, 2004, *ApJ*, 616, 40.
Genzel, R., and 6 co-authors, 2004, *ApJ*, 584, 633.
Glazebrook, K., and 11 co-authors, 2004, *Nature*, 430, 181.
Hu, E., and 7 co-authors, 2002, *ApJLett*, 568, 75
Kodaira, and 44 co-authors, 2003, *PASJ*, 55, 17.
Kogut, A., and 12 co-authors, 2003, *ApJS*, 148, 135.
Spergel, D., and 16 co-authors, 2003, *ApJS*, 148, 175.
Strolger, L.-G., and 35 co-authors, 2004, *ApJ*, 613, 200.
Walter, F., and 7 co-authors, 2004, *ApJL*, 615, 17.